EFFECTS OF STANDS OF BLACK PINE (*Pinus nigra* A r n.) AND ALEPPO PINE (*Pinus halepensis* M i l l.) ON THE PROTECTION OF SOIL FROM EROSION

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Abstract

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This paper presents the results of research into the effects of stands of black pine (*Pinus nigra* A r n.) and Aleppo pine (*Pinus halepensis* M i l l.) on the protection of soil from rain-induced erosion. Research was conducted in the watershed of the torrent Suvava at Muć in experimental plots B_4 and B_5 inhabited by old stands of black pine at an inclination of 32°, and in the watershed of the torrent Rupotine near Solin in experimental plots B_8 and B_9 containing preserved and burnt stands of Aleppo pine at inclinations of 26 and 20°. The estimated mean annual values of surface runoff in old and open stands of black pine with completely preserved humus accumulative horizon covered with thick grass, at an inclination of 32° (plots B_4), were 16.17 mm/m^2 (161.7 m^3/ha), with the runoff coefficient of 0.015 and soil loss of 0.0107 t/ha. Surface runoff in fully canopied stands of black pine and no grass cover, at an inclination of 32° (plot B_5), amounts to 31.65 mm/m^2 (316.1 m^3/ha), with the runoff coefficient of 0.027 and soil loss of 0.0196 t/ha.

In the fully canopied preserved stands of Aleppo pine, at an inclination of 26° (plot B_8), surface runoff amounts to 6.23 mm/m^2 (62.3 m^3/ha), with the runoff coefficient of 0.0087 and soil loss of 0.044 t/ha, and in the burnt area at an inclination of 20° (plot B_9), surface runoff amounts to 35.51 mm/m^2 (355.1 m^3/ha), with the runoff coefficient of 0.0478 and soil loss of 19.93 t/ha.

According to the results,, erosion-induced soil loss in the burnt forest area at an inclination of 20° is 463 times greater than under the preserved stands of Aleppo pine at an inclination of 26°.

Key words: karst, erosion, experimental plots B_4, B_5, B_8 and B_9, stands of black pine, stands of Aleppo pine, burnt areas, rainfall, surface runoff, soil loss

Introduction

Of the total Mediterranean karst area in the Republic of Croatia covering 15 389 km^2, about 95% is subjected to different intensities of water-induced soil erosion, of which severe erosion accounts for 40%. Accordingly, the area is highly threatened by erosion, while some of the parts are completely degraded. The ecologically very sensitive area at high risk from erosion, soil degradation and vegetation devastation contains 668 torrents with a total watershed area of 3024 km^2, which makes it one of the largest torrent areas in Croatia (Topić, Leko,1987; Mičetić, 2000; Topić, Butorac, 2005). The annual soil loss, or the quantity of soil that is irreversibly carried into the Adriatic Sea, has been estimated at 1140 ha with a layer of 20 cm in depth. Since the process of soil formation on karst, as an irreplaceable natural resource, is very slow and arduous, the issue of its protection is of utmost importance. With these reasons in mind, the Department of Forestry of the Institute for Adriatic Cultures and Karst Amelioration in Split launched scientific-research activities dealing with erosion and protection of soil on karst in 1964. In 1971, the first permanent experimental plots with measuring instruments were established in torrent watersheds in the Mediterranean karst area. They were aimed at obtaining original data on fundamental features of water-induced erosion using modern stationary methods.

The experimental plots were set up at different inclinations, with different geological and pedological characteristics and under different plant cover. Research results to date have been published in several papers (Topić, 1987, 1995, 1996, 2001, and others). Research carried out in Dalmatia (Martinović et al., 1978) revealed several forms of harmful changes in the soil caused by forest fires. A number of papers in the world and Croatia in recent years have dealt with the role of vegetation, forests in particular, and the hydrological regime, either in terms of water resource protection or its utilization. Impacts of forests on precipitation runoff, retention of rainfall in tree crowns and absorption of water by forest duff and friable and permeable forest soil have been studied (Prpić, 2001; Prpić et al., 2005; Gubka, 2005; Kantor, 2005; Klimo, Kulhavy, 2005; Komlenović et al., 1992; Matić et al., 2005; Tikvić, Seletković, 2003; Vicha, 2005).

The paper discusses research results of the effects of black pine stands and preserved and burnt Aleppo pine stands growing at varying inclinations and in diverse climatic and edaphic conditions on surface runoff and protection of soil from erosion.

Material and methods

Research was conducted in experimental plots B_4, B_5, B_8 and B_9 set up in torrent watersheds of the eu-Mediterranean and sub-Mediterranean karst area in the Republic of Croatia.
The plots B_4 and B_5 are in the Suvava Torrent watershed near Muć (Photo 1) in the area of Modraš. They are situated between 43°42´7.28˝ N and 16°27´3.18˝ E at an altitude of 550 m at western exposition and inclination of 32°. They are made up of marly limestone with shallow and skeletal brown soil (Calcocambisol).

Plot B_4 is in a thinned part of the black pine stand. The humus accumulation horizon covered with dense grass has been completely preserved. Plot B_5 is in pure and mature stands of black pine with complete canopy and very low participation of autochthonous species in the lower layer (Photo 2). These forests cover a part of the Suvava torrent and have a predominantly protective anti-erosion function.

Plot B_8 is situated in the old preserved stands of Allepo pine in Rupotine area, between 43°30´45˝ N and 16°30´05˝ E, 227 m above the sea in eastern exposition and inclination of 26°. It is covered with brown soil on colluvial breccia marly limestone. These forests cover a part of the torrent watershed of Rupotina and have a primarily anti-erosion role (Photos 3, 4).

Photo 1. Stand of black pine stand in the watershed of the torrent of Suvava, with overflow for limnigraphic monitoring of flow and sediment transport.

Photo 2. Plot B_5 is situated in a black pine stand with complete canopy and an inclination of 32°.

Photo 3. Aleppo pine stand in the watershed of the torrent of Rupotine with barriers in the torrent bed.

Photo 4. Plot B_8 in the stand of Aleppo pine at an inclination of 26°.

Photo 5. Burnt stand of Aleppo pine in 2001, Kučine area.

Photo 6. Plot B_9 in a burnt stand of Aleppo pine in Kučine area two years later, inclination 20°.

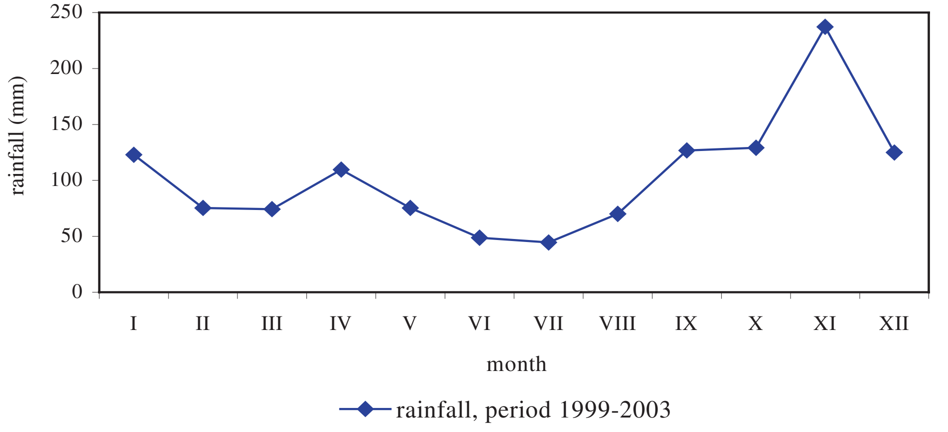
Plot B_9 is situated in a burned area of Aleppo pine in Kučine (Photo 5) between 43°31'48.5" N and 16°32' 25" E, at an altitude of 212 m with western exposition and inclination of 20°. Before the fire in 2001, the stand consisted mainly of Aleppo pine with sporadic cypresses aged 29. The geologic plot is homogenous, built of marly limestone overlaid by eroded Rendzina on marl (Vrbek, 2002). There is natural succession of forest vegetation. The regenerated Aleppo pine is accompanied with autochthonous maquis elements (Photo 6).

According to the data by Seletković, Katušin (1992), in Köppen's classification the area of Muć has a climate type Cfsax˝ characterized by annual rainfall of 1200 mm and annual temperature of 13.1°C. This is a temperate rainy climate with hot summers and a mean monthly temperature above 22 °C. The rainy season has a spring and autumn-winter maximum, and the driest part of the year is in the warm season.

Type Csa encompasses the area of Solin and Split, where research was done in stands of Aleppo pine. It is characterized by mild winters and dry summers with at least three times as much rainfall in the wettest winter month as in the driest summer month. The quantity of rainfall in the driest month is less than 40 mm. The mean annual rainfall amounts to 936 mm and the mean annual temperature is 15.5 °C. The summers are hot, dry and clear.

Accordingly, the climate in this area is principally characterized by high temperature degrees and low annual amplitudes, longer duration of sunshine and an uneven distribution of precipitation, of which 45% occur during the vegetation period. Low amounts of precipitation in the vegetation period are responsible for aridity of the Mediterranean area. These climatic features clearly discriminate this area from the continental part of Croatia.

In the plots supporting the stand of black and Allepo pine measurements were done on vegetation, leaf litter samples were taken and pedologic soil profiles were taken and analyzed in the laboratory. During the observed period, erosion effects of precipitation were monitored and directly measured in the experimental plots of 50 and 100 m^2, each with their storage. Impacts of black pine (plots B_4 and B_5), of preserved stands of Aleppo pine (plot B_8) and of burnt areas on the protection of soil from rain-induced erosion were studied. The plots were walled off with cement and metal fence. The fence was set up so as to prevent lateral water from reaching the experimental plots and curb uncontrolled runoff. A container intended to intercept erosion deposits was set up in the lower part of the plot. Data were entered into the Meteorological Station Monitoring Ledger every day at 7 o'clock obtained with measuring instruments (thermograph, thermometer, ombrograph, rain measuring instrument) positioned in the experimental plots. Quantities of water were measured in the storages and samples were taken on erosion days for laboratory analyzes.



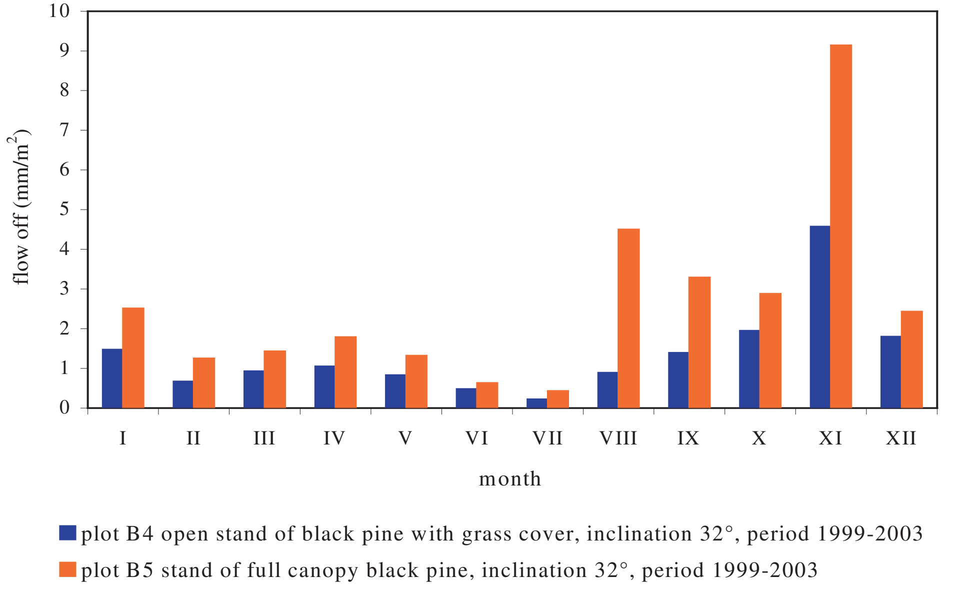


Fig. 1. Mean monthly values of rainfall and surface runoff in experimental plot in stands of black pine.

Results and discussion

Surface runoff and soil loss in stands of black pine

During 1999 and 2003, two experimental plots (B_4 and B_5) accounting for 10.7% of the total watershed area and inhabited by cultures of black pine were established in the watershed of the torrent Suvava near Muć. The watershed covers an area of 1823 ha and is situated in the belt between 460 and 961 m above the sea. Erosion activity of precipitation water is directly monitored in these plots. The annual precipitation quantities in the plots ranged between 1083.1 and 1396.5 mm and the mean annual value was 1238.9 mm. Runoff and soil loss were caused by precipitation from 8.9 to 90.0 mm. Of 448 rainy days in all, 90 were erodible, with precipitation responsible for runoff. Mean monthly rainfall values and runoff in plots B_4 and B_5 for the observed period are given in Fig. 1.

From the data quoted it can be concluded that the mean monthly values of surface runoff range within the following limits: in plot B_4 (a clearing in the old stand of black pine with a completely preserved humus accumulation horizon, overgrown by a thick sedge cover, inclination 32°) from 0.43 to 9.14 mm. Surface runoff coefficients in plot B_4 are from 0.0027 to 0.1389 and in plot B_5 from 0.0041 to 0.2516. The mean annual values of surface runoff are as follows: in the old and open stand of black pine overgrown by a grass cover – 16.17 mm/m^2 (161.7 m^3/ha), with the runoff coefficient of 0.017; in the old stand of black pine with a complete canopy – 31.65 mm/m^2 (316.5 m^3/ha), with the runoff coefficient of 0.032.

The percentage of surface runoff in the plots set up in the stands of black pine is low. Interception, evaporation and infiltration of water in the soil amounts to as much as 96.8% annually in the plot supporting the old stand of black pine with full canopy and an inclination of 32°. The values of mean monthly soil losses are shown in Fig. 2.

For plot $B_{4,}$ erosion losses (quantities of dry mud eroded from the plot into the container) range from 0.0044 in July to 0.3699 g/m^2 in November and for plot B_5 from 0.0149 in July to 0.4047 g/m^2 in April. For the observed period the mean annual values of soil loss in the plots under the culture of black pine were: under the old cleared black pine cultures with a thick grass cover at an inclination of 32°, 1.1603 g/m^2 or 0.0116 t/ha, and under the old black pine with a complete canopy at an inclination of 32°, 2.0425 g/m^2 or 0.0204 t/ha.

Maximum annual values of erosion soil losses in plot B_4 were 1.8376 g/m^2 and in plot B_5 they were 5.404 g/m^2 (0.054 t/ha).

Table 1 shows surface runoff and soil losses in the stands of black pine by erodible days. As seen in Table 1, there were 14 erosion incidents in 2003. The highest quantity of rainfall in that year and the largest runoff (21.58 mm/m^2) and soil loss (0.00442 t/ha) were recorded in plot B_5 on November 2. The rain falling from 1st to the 2nd of November had high intensity of 15.43 mm/hour and very high intensity of 23.1 mm/hour from 21.00 to 00.20 and duration (from 16.50 to 19.10, from 21.00 to 00.20, and from 04.00 to 06.10). The situation was further aggravated by the rains occurring from 20th to 31st October, which completely saturated the soil and led to filtration processes. As a result, the experimental plots under the stand of black pine underwent increased surface runoff and soil erosion on the 2nd of November.

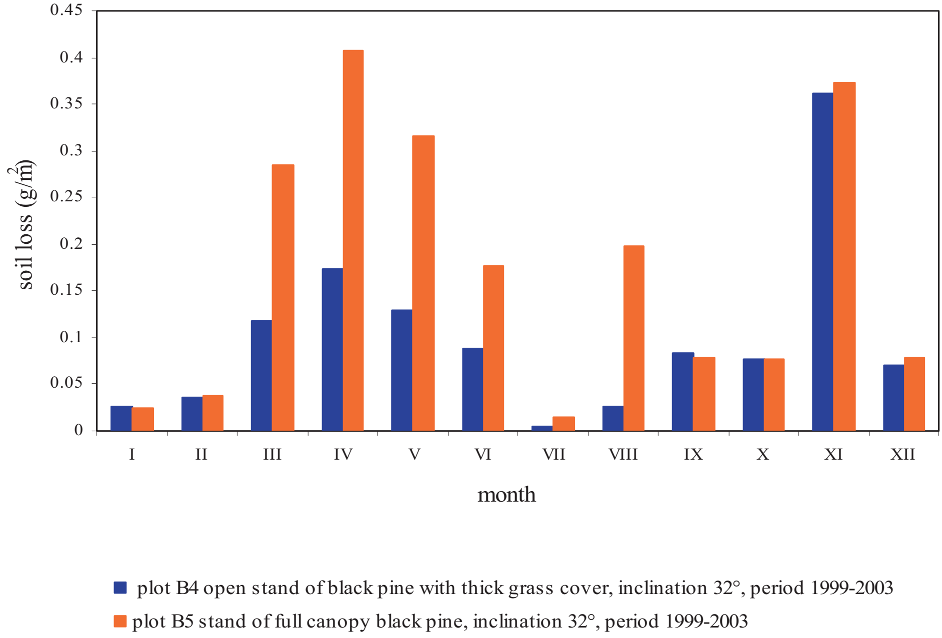


Fig. 2. Mean monthly values of soil loss in the experimental plots in the stands of black pine.

Precipitation, surface runoff and soil losses on 29th November and on other erodible days are similar to the above case.

According to Table 1, the total soil loss in experimental plots B_4 and B_5 in the mentioned year amounted to 0.0097 or 0.0107 t/ha, which is significantly below the tolerated annual loss. Consequently, there is no risk or erosion or it is almost negligible.

However, if the soils at such an inclination were to lose stands of black pine, or the vegetation cover, the risk of erosion would be extremely high or catastrophic.

Surface runoff and soil loss in preserved and burnt stands of Aleppo pine

As part of research into the effects of forest vegetation on the protection of soil from erosion, experimental plots were established in the area of Split and Solin in early 2002 at different inclinations and different geological and pedologic characteristics in preserved and burnt stands of Aleppo pine.

Plot B_8 is situated in old preserved stands of Aleppo pine of eastern expositon and inclination of 26° in the watershed of the torrent Rupotina. Its perimeter encompasses and area of

T a b l e 1. Surface runoff and soil loss in experimental plots B_4 and B_5 in the stands of black pine (2003).

Date of erosion occurrence 2003	Rainfall mm/m^2	Duration of rainfall h^{min}	Intensity of rainfall mm/h	Open stand of black pine with grass cover plot B_4		Stand of fully canopied black pine plot B_5	
				Inclination 32°			
				Flow off mm/m^2	Soil loss t/ha	Flow off mm/m^2	Soil loss t/ha
07.01.	35.0	10^{40}	3.28	0.60	0.00012	1.34	0.0009
09.01.	20.2	4^{50}	4.25	0.53	0.00015	0.89	0.00013
22.01.	27.0	10^{40}	2.53	0.53	0.00009	0.89	0.00010
31.01.	30.8	16^{15}	1.83	0.53	0.0009	1.24	0.00008
05.02.	22.2	10^{50}	2.05	0.53	0.00001	1.42	0.00010
30.06.	30.0	1^{10}	25.71	0.53	0.00034	0.60	0.00013
05.07.	37.0	0^{40}		0.35	0.00022	0.88	0.00074
06.10	39.0	12^{30}	3.12	1.06	0.00009	1.24	0.00025
23.10.	26.6	18^{40}	1.43	0.53	0.00014	0.88	0.00027
02.11.	90.0	5^{50}	15.43	4.78	0.00299	21.58	0.00436
25.11.	28.1	9^{40}	2.91	0.35	0.00139	0.53	0.00333
28.11.	18.0	8^{30}	2.12	0.53	0.00122	0.88	0.00059
29.11.	35.1	11^{55}	2.95	0.88	0.00159	1.42	0.00037
31.12.	31.8	24^{00}	1.32	0.71	0.00129	0.92	0.00016
Σ				12.44	0.00973	34.71	0.01070

the area 542 ha above Solin and Klis under the mountain Kozjak at altitudes between 5 and 650 m (Photo 4). The lower torrent positions belong to holm oak (*Quercetum ilicis*), while the higher are at a transition towards the belt of oriental hornbeam (*Carpinetum orientalis*). The quantity of rainfall in this plot amounted to 826.3 mm between 22nd August 2002 and 22nd August 2003. Runoff and soil losses were caused by rainfall from 18.3 to 68.6 mm (Table 2). Of 78 rainy days in all, 14 were erodible. Data on mean monthly values of rainfall and runoff in plot B_8 are shown in Photo 3. It can be concluded from the data that the mean monthly values of surface runoff were between 0 and 2.03 mm. The mean annual values of surface runoff in the plot in the first year of research amounted to 6.23 mm/m^2, with the runoff coefficient of 0.0087. In erodible days the coefficient ranged between 0.0029 and 0.0556, and 4.395 g/m^2 of dry sand was washed away (0.044 t/ha).

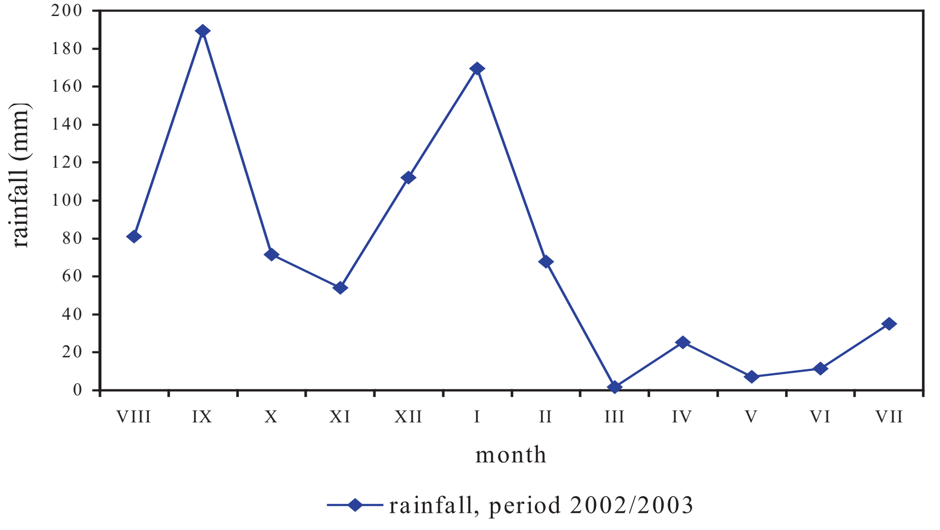
Plot B_9 is situated immediately next to the watershed of the torrent Rupotina in the burnt stand of Aleppo pine in Kučine. The altitude is 212 m above the sea, the exposition is western, and the inclination 20° (Photo 6). Before the fire in 2001 the 29-year-old stand was mainly covered with Aleppo pine with some cypresses. The fire was followed by natural succession in which Aleppo pine was regenerated and some autochthonous maquis ele-

T a b l e 2. Surface runoff and soil loss in experimental plots B_8 and B_9 in the preserved and burnt stands of Aleppo pine (2002/2003).

Date of beginning of erosion 2002/2003	Rainfall mm/m²	Duration of rainfall h min	Intensity of rainfall mm/h	Preserved stand of Aleppo pine plot B_8		Burnt stand of Aleppo pine plot B_9	
				Inclination 26°		Inclination 20°	
				Runoff mm/m²	Soil loss t/ha	Runoff mm/m²	Soil loss t/ha
22. 8.´02	14.1			0.42	0.00563	3.80	0.02511
22.-24.8. ´02	150.6			2.03	0.03045	14.56	19.51409
11. 10.´02	25.5	3^{10}	8.05	0.76	0.00405	2.43	0.09665
12. 10.´02	20.6	9^{50}	2.09	0.34	0.00029	1.05	0.01911
03. 11.´02	20.4	3^{50}	5.32	0.42	0.00083	0.49	0.003563
23. 11.´02	21.2	4^{35}	4.63	0.17	0.00016	1.24	0.01969
01. 12.´02	18.6	6^{10}	3.02	0.17	0.00015	0.65	0.01987
04. 12.´02	19.7	10^{50}	1.82	0.09	0.00010	0.49	0.00249
29. 12.´02	21.9	3^{30}	6.26	0.09	0.00011	1.25	0.04518
01. 01.´03	14.5	11^{50}	1.22	-	-	0.32	0.00089
06. 01.´03	18.3	1^{20}	13.73	0.39	0.00098	1.94	0.03293
07. 01.´03	27.6	8^{00}	3.45	0.17	0.00016	3.48	0.10611
10. 01.´03	25.3	5^{00}	5.06	0.34	0.00028	0.49	0.00248
22. 01.´03	32.3	6^{30}	4.97	0.42	0.00039	0.57	0.00476
30. 01.´03	8.2	7^{10}	1.14	-	-	0.40	0.00270
31. 01.´03	5.9	1^{00}	5.89	-	-	0.41	0.00346
05. 02.´03	65.7	15^{30}	4.24	0.42	0.000396	1.70	0.02678
22. 04.´03	9.2	18^{35}	0.49	-	-	0.24	0.00282
Σ	519.6			6.23	0.04395	35.51	19.92668

ments occurred. In the first year of research and the second after the fire, of 78 rainy days 18 days were erodible in this experimental plot. The mean monthly values of surface runoff ranged from 0 to 14.56 mm (Fig. 3). The annual value of surface runoff amounted to 37.81 mm/m², with the runoff coefficient of 0478. The maximum runoff coefficient was 0.2697. A quantity of 19.927 t/ha of dry mud was washed away (Table 2).

The largest quantity of eroded deposits of 19.51 t/ha was recorded on 24th September 2002, following rainfall of 150.6 mm lasting for three days. There are no data on precipitation intensity since the plot had only been established and there were no measuring instruments (ombrograph, rain measuring instrument). For this reason, precipitation data from the main meteorological station Split-Marjan were used for this period until measuring instruments were installed in plots B_8 and B_9. The mentioned eroded deposits were caused by three



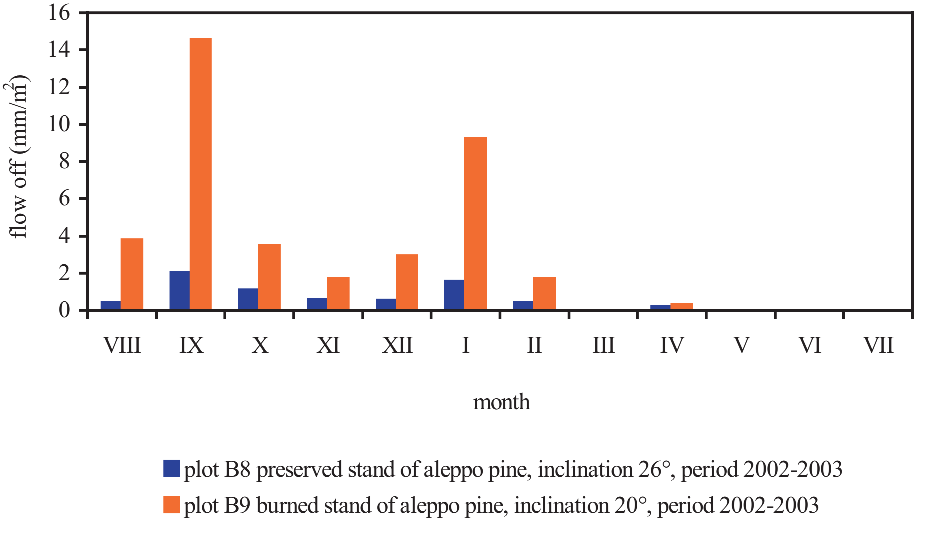


Fig. 3. Average monthly values of rainfall and surface runoff in experimental plots in the preserved and burnt stands of Aleppo pine.

rains occurring on the 22nd, 23rd and 24th September 2002. The first rainfall quantity was 42.0 mm, the second 68.6 mm, and the third 40.0 mm. As it cannot be determined which of the rains caused stronger erosions, all three rains together are regarded as causes of the erosion quantity amounting to 19.51 t/ha, accounting for 97.9% of the entire annual erosion deposits. The reason for such high erosion values in plot B_9 lies in the current condition of the vegetation cover. In such erodible soils, which were left bare from forest vegetation after the fire, the rains in August and September completely saturated the soil and provided conditions for surface runoff and high values of erosion deposits.

The importance of forest vegetation on karst for the protection of soil from erosion is best seen if data in Table 2 on surface runoff and erosion in experimental plots B_8 and B_9 are compared. Although the plots have almost identical geological and pedologic characteristics and receive the same quantity and intensity of rainfall, the annual value of surface runoff in plot B_8 under the stands of Aleppo pine with a complete canopy and inclination of 26° amounted to 6.23 mm/m^2, whereas soil loss amounted to 0.044 t/ha. In plot B_9 with unprotected bare ground after the fire, the annual value of surface runoff was 35.51 mm/m^2 and soil loss was 19.93 t/ha. The reason for no erosion or for erosion with very minor soil losses in plot B_8 is the presence of forest vegetation, that is, the preserved stands of Aleppo pine. Accordingly, forests of black and Aleppo pine are decisive factors in the protection of soil from erosion, particularly in steep erodible areas. This has been confirmed by research conducted in permanent experimental plots established in the watershed of the torrent Suvava and the watershed of the torrent Rupotina.

Conclusion

Based on research into the impact of forest vegetation on the protection of soil from erosion in the experimental plots under black and Aleppo pine in the watershed of the torrents Suvava and Rupotina, the following can be concluded: stands of Aleppo and black pine in these watersheds have a significant and distinctly positive role in protecting the soil from erosion. Their crowns inhibit the destructive actions of raindrops and intercept a large quantity of precipitation. The rest of the rainfall passes through the crowns to the surface of friable and permeable forest soil, which absorbs them and infiltrates them more easily. Surface runoff in the studied stands is low and soil losses are much below the tolerated annual erosion. Consequently, there is no risk of erosion or the risk is insignificant.

The mean annual values of surface runoff in old and open stands of black pine with a preserved humus accumulation horizon covered with thick grass cover, lying at an inclination of 32° (plot B_4), amount to 16.17 mm/m^2 (161.7 m^3/ha). The runoff coefficient is 0.017 and soil loss 0.0116 t/ha. In the stands of black pine with a complete canopy and no grass cover lying at an inclination of 32° (plot B_5), surface runoff amounts to 31.65 mm/m^2 (316.5 m^3/ha). The runoff coefficient is 0.032 and soil loss is 0.0204 t/ha.

In the preserved stands of Aleppo pine with a complete crown cover at an inclination of 26° (plot B_8), surface runoff amounts to 6.23 mm/m^2 (62.3 m^3/ha). The runoff coefficient is 0.0087 and soil loss is 0.044 t/ha. In the burnt area with an inclination of 20° (plot B_9) surface runoff amounts to 35.51 mm/m^2 (355.1 m^3/ha). The runoff coefficient is 0.0478 and soil loss is 19.93 t/ha. This is several times more than tolerated erosion. According to the results, erosion-induced soil loss in burnt areas with an inclination of 20° is 463 times higher than under the preserved stands of Aleppo pine at an inclination of 26°.

Translated by the authors

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